CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-132
September 10, 1982

1. Name of faults

Konocti Bay fault, Collayomi fault, Big Valley fault, and other unnamed fault segments in the Clear Lake area.

2. Location of faults

Clearlake Highlands, Kelseyville, Lower Lake, The Geysers, and Whispering Pines 7.5-minute quadrangles, Lake County (figure 1).

3. Reason for evaluation

Part of 10-year fault evaluation program (Hart, 1980).

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5. Review of available data

The Clear Lake area is a region of structural and lithologic complexity. The Clear Lake volcanics, which range in age from 2.1 my to 11,000 yrs BP (Donnelly-Nolan, et al., 1981), have been extruded onto rocks primarily of the Franciscan Complex and Great Valley Sequence (Brice, 1953; Hearn, et al., 1976, 1981). These volcanic rocks range in composition from basalt to rhyolite, with dacite the most abundant rock type (Donnelly-Nolan, et al., 1981). Thus, viscous lava flows form many linear and steep scarp-like features in the Clear Lake volcanic field.

The Clear Lake volcanics are the youngest volcanic rocks in a series that is progressively older to the south. Several theories explaining the origin of the Clear Lake volcanics have been proposed. Hearn, et al. (1981) favor a stationary mantle hot spot that has generated a series of Tertiary and Quaternary volcanic centers as the North American plate migrated relatively southward across the hot spot. McLaughlin (1981) relates the occurrence of the Clear Lake volcanics to the northward migration of the Mendocino triple junction. The accompanying crustal extension caused magma leakage along a propagating land-bound transform fault system. Isherwood (1981) theorizes that subducted Farallon plate material was detached by the northward migration of the Mendocino triple junction. Because the driving force of subduction ceased, the subducted material sank vertically due to gravitational forces. Subsequent melting of the boundaries of the subducted plate convectively transferred heat to the overlying rocks, causing an upward rise of magma. Donnelly (1977) and Donnelly-Nolan, et al. (1981) postulate that propagation of the San Andreas fault system produced zones of weakness or tears deep in the earth's crust. The resulting lower pressure in the upper mantle allowed partial melting, producing a thermal anomaly which melted crustal rocks.

Brice (1953) was the first to map the Clear Lake region (Lower Lake 15-minute quadrangle) in detail, although mapped faults are extremely simplified and will not be evaluated in this Fault Evaluation Report (FER). McNitt (1968) mapped the Kelseyville 15-minute quadrangle, but again the faults are too generalized to be evaluated in this FER. Hearn, et al. (1976) have mapped the Clear Lake area in detail, including the Lower Lake, Clearlake Highlands, Clearlake Oaks, Kelseyville, Whispering Pines, Lucerne, and The Geysers 7.5-minute quadrangles. Five quadrangles (Clearlake Highlands, Lower Lake, Kelseyville, Whispering Pines, and The Geysers) will be evaluated in this FER (figures 2a, 2b, 2c, 2d, 2e). Herd (in press) mapped late-Quaternary faults in the Clearlake Highlands, Kelseyville, and Lower Lake 7.5-minute quadrangles (figures 3a, 3b, 3c).

Hearn, et al. (1976) have mapped the Clear Lake area in detail and depict an extremely complex pattern of faults (figures 2a-2e). However, the majority of faults mapped by Hearn, et al. (1976) are based on interpretation of aerial photographs with only minimal field confirmation (Donnelly-Nolan, p. c, 8-17-82). Thus, the displacement of geologic units mapped by Hearn, et al. (1976) is, in many instances, only inferred. Hearn, et al. (1976) do not classify faults with respect to activity, but they do indicate scarp orientation, closed depressions, and fault plane geometry when the data is available. Hearn, et al. (1981) state the Clear Lake area fits a system of deformation related to a right-lateral northwest-southeast strike-slip couple (Wilcox, et al., 1973) that has locally been overprinted by features related to volcanism.

Herd (in press) mapped principal late-Quaternary faults in the Clear Lake region based on interpretation of 1942 USGS air photos. Herd's maps are not annotated and he has not field checked fault traces interpreted from air photos (p. c., 8-82) . Herd believes that faults in the Clear Lake area are primarily related to caldera subsidence (p. c., 8-82).

(Fault names in this report are all informal, with the exception of the Konocti Bay fault zone and the Collayomi fault zone, and are used only to simplify discussion)

Konocti Bay Fault Zone

The Konocti Bay fault zone (KBFZ) strikes about N25° - 30°W and is located south and east of Mt. Konocti (figures 2a, 3a). The KBFZ ranges in width from about 1,500 feet to 10,000 feet wide. Displacement along the fault zone is predominantly normal, although a component of right-lateral strike-slip displacement is reported by Hearn, et al. (1981). Young pyroclastic deposits (bp unit of Hearn, et al., 1976) ranging in age from 84,000 yrs BP to 11,000 yrs BP are offset along the northwestern segment of the KBFZ (figure 2a). A complex zone of both north-northwest and northeast-trending faults are mapped in the Wheeler Point area and are considered to be a part of the KBFZ by Hearn, et al. (1976) (figure 2a). Some faults in the Wheeler Point area offset young pyroclastic deposits of Hearn, et al. (1976) (figure 2a). A small alluvial fan at the west end of Thurston Lake is inferred to be offset by Hearn, et al. (1976) (figure 2a). Hearn, et al. (1976) indicate that most fault strands within the KBFZ are well-defined (figure 2a).

It is critical to know the specific age of the bp unit that is offset by the KBFZ. Hearn, et al. (1976) indicate that the 11,000 yr BP age for the bp unit is based on an ash bed from a drill core located about midway between Fraser Point and Pirates Cove (Sims and Rymer, 1975) (figure 2a). Thus, the precise age of the bp unit is not known where displaced by the KBFZ (Donnelly-Nolan, p.c., 8-82). (Holocene age indications depicted on figures 2a, 2b, 3a, and 3b are approximations rather than firmly documented age determinations).

Although Hearn, et al. (1976, 1981) do not document geomorphic evidence of fault recency, they do state that the KBFZ is probably active, based on youthful geomorphic features indicating at least late-Pleistocene activity and the occurrrence of earthquakes in close proximity to the KBFZ.

The Konocti Bay fault zone mapped by Herd (in press) is, in general, similar to the mapping of Hearn, et al. (1976), although significant differences in detail exist (figure 3a). The principal trace of the KBFZ along the east flank of Mt. Konocti from section 16, T13N, R8W southeast to section 34, T13N, R8W is similar to mapping by Hearn, et al. (1976), but faults in the Wheeler Point area mapped by Herd are more complex (figures 2a, 3a). Herd does not map the KBFZ southeast of section 35, T13N, R8W (figure 3a).

Sims (1982) indicates that a northeast branch of the KBFZ is located across the mouth of Konocti Bay, probably close to the concealed fault trace mapped by Hearn, et al. (1976) (locality 1, figure 2a). A seismic reflection profile and a fathogram indicate that the lake bottom locally is offset by the fault, suggesting Holocene activity.

Collayomi Fault Zone

The Collayomi fault zone, first mapped by Brice (1953) in the northern Collayomi Valley, is a N40°W trending zone of faults that generally bound the southwestern extent of the Clear Lake volcanics (Hearn, et al., 1976) (figures 2b, 2d). Hearn, et al. (1981) indicate that the predominant style of offset is normal along the Collayomi fault zone. Offset in a right-lateral sense is reported along a fault segment in the Collayomi fault zone (locality 2, figure 2b). Volcanic rocks (Thurston Creek rhyolite) about 0.5 to 0.6 my old are offset approximately 1,200 feet in a right-lateral sense (Donnelly, et al., 1976; Hearn et al., 1976; 1981). However, Hearn, et al. (1976) map a concealed fault at the location where the apparent right-lateral offset occurs. The 1,200 feet of displacement is based on the projection of the Thurston Creek rhyolite and Poison Springs andesite contacts into the concealed fault. Thus, the magnitude of right-lateral offset is based on inferred evidence.

The youngest formation mapped as offset along the Collayomi fault zone is a late-Pleistocene terrace deposit (tbr formation of Hearn, et al., 1976) located in the Cobb Valley area (figures 2c, 2d). At one location along Bottle Rock Road silca-carbonate rock (altered serpentine) was thrust over the tbr unit. Some volcanic clasts in the terrace deposit were correlated with volcanic rocks about 0.6 my old (McLaughlin, p.c., 8-82). Hearn, et al. (1976, 1981) and Donnelly, et al. (1976) state that the Collayomi fault zone is probably active based on linear topographic features, deflected drainages, the presence of linear bodies of serpentine along the fault zone, and the occurrence of microseismicity. However, there is no direct evidence of activity during Holocene time along the Collayomi fault zone (McLaughlin, p.c., 8-82).

Principal faults of the Collayomi fault zone do not offset late-Pleistocene terrace deposits (t_2 unit of Hearn, et al., 1976) to the north (locality 3, figure 2b). To the southeast, alluvium in the Collayomi Valley is mapped in fault contact by Brice (1953). The mapping of Hearn, et al. (1976) does not extend far enough south to include the Collayomi Valley and the mapping of Fox, et al. (1973) does not extend far enough to the northwest. Swe and Dickenson (1970) have mapped in the area including the Collayomi Valley, but they were principally concerned with pre-Quaternary structure and tectonics and do not map Pleistocene and Holocene deposits in detail.

Herd (in press) maps a short, northwest-trending fault zone through Camel Back Ridge (figure 3b). Faults in this area mapped by Herd are similar to faults mapped by Hearn, et al. (1976) (figure 2b). However, Herd does not consider the Camel Back Ridge faults to be a part of the Collayomi fault zone (p.c., 8-82). Southeast of Camel Back Ridge, Herd did not observe geomorphic evidence of recent faulting along the Collayomi fault zone. The Collayomi fault zone is thought by Herd to be an older structure that has not had significant late-Quaternary movement (p.c., 8-82).

Big Valley Fault

The southern part of the Big Valley fault (Lake County Flood Control and Water Conservation district, 1967) is considered to be a splay of the Collayomi fault zone by Hearn, et al. (1976) (figure 2b). This fault is thought by Hearn, et al. (1976) to have had surface rupture during the 1906 San Francisco earthquake, based on this description of cracks by Lawson (p. 188, 1908):

> "About 3.75 miles south of Kelseyville on the road to Lower Lake, at the ranch of Mr. M.E.D. Bates, is a crack varying in width from 1 to 6 inches. It crosses the road about 200 feet below the house. At the right of the road going south it crosses the creek and can be

seen no further. At the left of the road it passes up the hill toward Uncle Sam Mountain (Mt. Konocti) for about a mile, but is not continuous. Near the road two small trees standing on the crack have been partly uprooted and a fence post has been thrown out entirely. The rock thru which the crack passes is alluvium and a loose, unconsolidated conglomerate. It apparently does not pass thru the hard Franciscan rocks. In places there are as many as 10 parallel cracks, separated by intervals of 5 to 10 feet, which could be traced for only short distances."

However, the precise location and nature of the cracks is somewhat ambiguous. A more compelling explanation of the cracks would seem to be secondary shaking effects in relatively unconsolidated material, based on the series of parallel cracks and the lack of fractures in bedrock. Youd and Hoose (1978) classify the cracks as "not clearly associated with landslides, lateral spreads, settlement, or primary fault movements."

The southern Big Valley fault mapped by Hearn, et al. (1976) is characterized primarily by a well-defined east-facing scarp that offsets 0.2 to 0.4 my old dacite (dk of Hearn, et al., 1976) (figure 2b). The Big Valley fault does not offset alluvium along its north-northwest trace (figure 2b).

Herd (in press) maps a north-trending fault that partly coincides with the southern Big Valley fault mapped by Hearn, et al. (1976) (figure 3b). However, Herd did not observe evidence of late-Quaternary offset south of locality 4 (figures 2b, 3b), and maps the northerly segment to be concealed by alluvium of Hearn, et al. (1976).

Northeast-trending Faults South and East of Mt. Konocti

There are several northeast-trending faults along the south and southeastern flanks of Mt. Konocti that have been mapped by both Hearn, et al. (1976) and Herd (in press) (figures 2a, 2b, 3a, 3b). This zone of faults is located west of the Konocti Bay fault zone in sections 16 and 21, T13N, R8W and trend southwest to Mt. Olive on the north and section 7, T12N, R8W on the south. Although both Hearn, et al. (1976) and Herd (in press) map these faults, significant differences in detail exist.

The faults at locality 5 (figures 2b, 3b) are characterized by well-defined backfacing scarps (Hearn, et al. 1976). These faults offset dacite of Mt. Konocti and latest-Pleistocene to Holocene pyroclastic deposits in an apparent normal sense, northwest side down.

Arcuate, concentric faults bounding the Ely Flat area mapped by Hearn, et al. (1976) offset young pyroclastic deposits (bp unit) at locality 6 (figure 2a). Herd (in press) also maps these faults, although he indicates that the faults are concealed along most of their surface trace (figures 3a, 3b).

Herd maps a well-defined northeast-trending fault as offsetting part of the cauldera boundary, probably in a vertical sense, west side down (locality 7, figure 3b). The northeast-trending fault is mapped as offsetting an alluvial fan by Herd. This fault may extend southwest to Mt. Olive as part of a discontinuous, complex zone of normal faults (figure 3b). Hearn, et al. (1976) also map these southwest-trending faults, although significant differences in detail exist (figures 2b, 3b).

A well-defined, north-trending zone of faults in sections 19 and 30, T13N, R9W is mapped by both Hearn, et al. (1976) and Herd (figures 2b, 3b). Herd maps a more complex zone of faults, but Hearn, et al. (1976) extend the fault zone about 1,500 feet farther north than Herd does.

Red Hill Road Fault

The Red Hill Road fault is a northwest-trending, fairly linear fault located from section 4, T12N, R8W southeast to sections 9 and 10, T12N, R8W (figures 2a, 2b, 3a, and 3b). Hearn, et al. (1976) map the fault as offsetting 0.5 my old rhyolite. Both Hearn, et al. (1976) and Herd map this fault with good agreement, but Herd did not observe geomorphic evidence of recent faulting southeast of section 9.

Faults in Lower Lake Quadrangle

Hearn, et al. (1976) mapped many faults of various orientations in the Lower Lake 7.5-minute quadrangle (figure 2e). Well-defined faults in the Quackenbush Mountain area and along the northeast flank of Schoolteacher Hill are mapped by both Hearn, et al. (1976) and Herd (figures 2e, 3c). The Quackenbush Mountain faults offset Pleistocene-age basalt against Plio-Pleistocene Cache Formation (Hearn, et al., 1976). A northwest-trending fault characterized by a northeast-facing scarp offsets Pleistocene basalt and Plio-Pleistocene Cache Formation (Hearn, et al., 1976) (locality 8, figures 2e, 3c). A short, northeast-trending fault along the north side of Burns Valley is delineated by a southeast-facing scarp in about 200,000-year-old terrace deposits mapped by Hearn, et al. (1976) (locality 9, figure 2e). This fault is concealed by recent alluvium, although Hearn, et al. map the contact between terrace deposits and alluvium as fault-controlled. Herd did not observe geomorphic evidence of recent faulting along the north side of Burns Valley (figure 3c).

Herd maps a short northeast-trending fault zone north of the Anderson Flat area (figure 3c). The faults are well-defined, but are confined to 0.4 my old dacite of Cache Creek (Hearn, et al. 1976). Herd does not map this fault zone south of Highway 53 (figure 3c). Hearn, et al. (1976) do not map these faults, but do map a northwest-trending fault cutting the dacite (locality 10, figure 2e).

Fault Classification Maps by Pampeyan and Bortugno

Pampeyan (1979) includes a portion of the Clear Lake area in his fault classification map (figure 4). The somewhat generalized fault traces are based on the mapping of Hearn, et al.(1976). Faults within the Konocti Bay fault zone are classified as Holocene-active, based on youthful geomorphic features and offset Holocene-age deposits. Additional faults or fault zones classified by Pampeyan include: northeast-trending faults along the south flank of Mt. Konocti, the southern Big Valley fault, and a short fault segment just east of Snows Lake (locality 11, figure 2d; figure 4). The Collayomi fault zone is classified as late-Pleistocene in age with no evidence of Holocene activity (figure 4).

Bortugno (1982) has also compiled a fault classification map for the Santa Rosa Quadrangle of the Regional Geologic Map Series. Faults classified as Holocene-active in the Clear Lake area generally are similar to the Holocene-active faults classified by Pampeyan (1979) (figure 4). Bortugno classifies the southern Big Valley fault and an arcuate fault bounding the Ely Flat area as late-Quaternary active (between 10,000 yrs and 700,000 yrs BP) rather than Holocene-active. Bortugno also indicates that the Collayomi fault zone has no evidence of Holocene activity.

Seismicity and Crustal Monitoring

The seismicity of the area near Clear Lake is dominated by epicenters concentrated along the northwest-trending Maacama fault zone and clustered in the vicinity of The Geysers, where the rate of seismicity is estimated to be about 45 times the regional rate (Ludwin, et al., 1982). Within the FER study area, there are two siginificant clusters of seismic events that occurred in September 1975 and August 1976 (figure 5). These seismic events are shallow (average about 4 km focal depth) and spatially could be associated with the Konocti Bay fault zone. Focal-plane solutions for selected events in September 1975 and August 1976 yielded a preferred right-lateral strike-slip solution along a northwest-trending near vertical fault plane along the west margin of the KBFZ and a preferred right-lateral strike-slip solution along a north-trending, near vertical fault plane on the east margin of the KBFZ (Bufe, et al., 1981) (figure 5). Stress vectors calculated for seismic events possibly associated with the KBFZ yield equal components of stress along both horizontal and vertical axes, indicating both strike-slip and normal components of displacement (McLaughlin, p.c., 8-82).

Hearn, et al. (1981) suggest that the Collayomi fault zone may be historically active due, in part, to felt earthquakes near the fault zone. However, there does not seem to be a spatial association of earthquake epicenters with the northwest-trending Collayomi fault zone (figure 5).

Large-scale geodetic measurements in The Geysers-Clear Lake area indicate a regional, right-lateral horizontal movement along northwest-trending fault systems, and vertical and horizontal compression of the deep geothermal reservoir system (Lofgren, 1981). However, detailed survey networks allowing monitoring of specific fault zones have not been established in the Clear Lake area. Thus, the assignment of creep movement to specific faults or increments of tilting to specific fault blocks cannot currently be made.

6. Air photo interpretation

Air photo interpretation by this writer of faults in the Clear Lake area is summarized on figures 2a, 2b, 2c, 2d, 2e, 3a, 3b, 3c. Because of the complexity of faulting in the Clear Lake area, the primary emphasis was to verify the mapping of Herd (in press) and Hearn et al. (1976) with respect to documenting evidence of recent fault activity, rather than compiling an independent interpretation. Geomorphic evidence of recent faulting has been annotated by this writer on figures 2a-2c and 3a-3c. Maps by Herd and Hearn, et al. (1976) are not annotated.

Dacite and rhyolite flows are the most common volcanic rocks in this area and characteristically are viscous, often forming scarp-like flow levees. Because the Clear Lake volcanic field is composed of very young and viscous rocks (Donnelly-Nolan, et al., 1981), many constructional volcanic features are preserved and tend to dominate the geomorphology of the area. Thus, certain geomorphic features critical in establishing recency of faulting, such as closed depressions, ponded alluvium, and well-defined escarpments, are commonly associated with constructional volcanic terrain in the Clear Lake area.

Konocti Bay Fault Zone

The KBFZ is generally well-defined and is associated with geomorphic features suggesting Holocene activity, such as backfacing scarps, sidehill benches, closed depressions, deflected drainages, and offset ridges (figures 2a, 3a). The KBFZ is thought by Hearn, et al. (1976) to be primarily normal. However, principal northwest-trending faults along the west part of the KBFZ are fairly linear, suggesting fault planes with near vertical dips. A component of right-lateral strike-slip displacement is suggested by right-laterally deflected drainages and linear sidehill benches (figures 2a, 3a). Both Herd (in press) and Hearn, et al. (1976) map this western trace with fairly good agreement, although the fault traces of Herd can be verified in detail.

The Wheeler Point area, considered to be a part of the KBFZ, is a very complex zone of both northwest- and northeast-trending faults. Displacement along faults is primarily normal, although right-laterally deflected drainages and sidehill benches along the eastern boundary of the KBFZ suggest a component of right-lateral strike-slip displacement (figure 3a). Most of the faults within the Wheeler Point area are well-defined and exhibit geomorphic evidence of probable Holocene activity (figures 2a, 3a). An alluvial fan at the west end of Thurston Lake seems to be offset by a strand of the KBFZ in a normal sense, west side up (figures 2a, 3a). Herd (in press) also maps a tonal lineament on the fan that I can verify using 1942 (USGS) air photos (figure 3a).

A northwest-trending fault in sections 12 and 13, T12N, R8W mapped by Hearn, et al. (1976) is probably the southern extent of the KBFZ (figure 2a). This fault segment is characterized by linear ridges, closed depressions, and deflected drainages that suggest Holocene activity. I did not observe geomorphic evidence of Holocene-active faults along the KBFZ south of section 13, T12N, R8W. Both Pampeyan (1979) and Bortugno (1982) indicate that a short, northwest-trending fault along the east margin of Snow's Lake is Holocene active. This is based on the mapping of Hearn, et al. (1976), which suggests Holocene alluvium is offset. I could not verify that a fault exists along the east side of Snow's Lake and Herd (in press) does not map late-Quaternary faults in this area.

Collayomi Fault Zone

The Collayomi fault zone is generally located along a N40°W trend within or near Cobb Valley (figures 2b-2d). Hearn, et al. (1976) state that displacement along the Collayomi fault zone is predominantly normal. However, the relatively narrow, linear surface trace of the fault zone suggests a vertical fault plane with predominantly horizontal displacement.

Faults in the Camel Back Ridge area mapped by both Hearn, et al. (1976) and Herd (in press) are well-defined and are characterized by geomorphic features suggesting Holocene activity, such as a sidehill bench, possible closed depression, and a linear trough, based on air photo interpretation by this writer (figures 2b, 3b). Southeast of Camel Back Ridge, the fault zone is not well-defined, fault traces being obscured by colluvium and landslides. The Collayomi fault zone south of Camel Back Ridge is located generally along Cobb Valley, so erosion rates and downslope movement may outpace surface displacement.

A fault mapped west of Boggs Lake by Hearn, et al. (1976) is characterized by an east-facing scarp in 0.8 my old andesite (locality 12, figure 2b). The fault is well-defined only at locality 12 where the lateral boundary of a landslide has enchanced the expression of the fault (figure 2b). It is not clear what geologic process has formed Boggs Lake. Hearn, et al. (1976) favor tectonic processes, while Herd favors volcanic processes.

There is no geomorphic evidence of systematic right-lateral displacement along the Collayomi fault zone of Hearn, et al. (1976). Linear ridges composed of serpentine help to define the Collayomi fault zone in sections 20, 28, and 33, T12N, R8W (figure 2b, 2c, 2d). Troughs, saddles, and a few closed depressions suggest recent activity along this segment of the Collayomi fault zone (figures 2c, 2d). However, the closed depressions are not clearly associated with faulting and are probably related to landsliding. The troughs and saddles may be erosional. A possible shutter ridge at locality 13 (figure 2c) has been breached, suggesting that Holocene displacement may not have occurred along this segment of the fault zone. Additional negative evidence of Holocene activity is suggested by the lack of deflection of the drainage just east of the shutter ridge (figure 2c, 2d). Large scale right-lateral deflections of Jones Creek (section 11, T11N, R8W) and Houghton Creek (section 11, T11N, R8W) occur along different strands of the Collayomi fault zone and may be erosional because most drainages that cross traces of the Collayomi fault zone are not offset or deflected (figures 2c, 2d).

A northeast-facing scarp at locality 14, (figure 2d; near Whispering Pines) coincides with a fault mapped by Hearn, et al. (1976). This fault is further delineated by linear springs. However, the fault juxtaposes serpentine against 1 my old rhyolite (Hearn, et al., 1976), and the scarp may be erosional.

There is no geomorphic evidence of recent faulting southeast of Whispering Pines. Brice (1953) maps a fault contact between alluvium and serpentine in the northwestern part of the Collayomi Valley, but there is no geomorphic evidence of recent faulting except for the somewhat linear hill front (figure 2d). This linear hill front is probably the result of lateral erosion along Putah Creek, rather than recent faulting. There is no geomorphic evidence indicating recent faulting along a southeastern projection of the fault into the Collayomi Valley.

Big Valley Fault

The Big Valley fault, considered by Hearn, et al. (1981) to be a branch of the Collayomi fault zone, is well-defined within 300,000- to 400,000-year-old dacite at locality 15 (figure 2b). Both Hearn, et al. (1976) and Herd agree fairly well in the location of this north-trending fault in section 24 and the northern part of section 25, T13N, R9W, where an east-facing scarp in dacite, with associated left-laterally deflected drainage and ponded alluvium define the fault (figure 2b, 3b). The fault is not well-defined north of locality 16 (figures 2b, 3b) and was not observed in the alluvium of Big Valley. Southeast of Herd's location (figure 3b), the fault is delineated by a tonal lineament and sidehill bench in dacite and late-Pleistocne lake deposits of Hearn, et al. (1976). No geomorphic evidence of faulting was observed in alluvium to the south.

Northeast-Trending Faults South and East of Mt. Konocti

Northeast-trending faults along the south flank of Mt. Konocti are well-defined and are characterized by geomorphic evidence of probable Holocene activity, such as ponded alluvium, vertically offset drainages, sidehill benches, and backfacing scarps (locality 5, figures 2b, 3b).

The fault zone from Mt. Olive northeast to the NE-1/4 of section 29, T13N, R8W is generally well-defined. Geomorphic evidence of possible Holocene activity includes closed depressions, ponded alluvium, a sidehill bench, a linear trough, and sharp, well-defined scarps (figures 2b, 3b). Geomorphic evidence suggesting Holocene activity along the southern-most zone of northeast-trending faults includes: deflected drainages, closed depressions, ponded alluvium, and a linear trough (figure 3b). No geomorphic evidence of recent faulting was observed along a northeast projection into the Ely Flat area.

Both Hearn, et al. (1976) and Herd (in press) map arcuate faults bounding all but the south side of the Ely Flat area (figures 2a, 3a). These faults, which are related to caldera collapse, are generally not well-defined (figures 2a, 3a). Because these faults probably form the boundary of a collapse feature, it would be expected that the faults would be obscured by their own rubble and the subsequent deposition of alluvium in the basin.

A north-trending zone of faults in sections 19 and 30, T13N, R9W is mapped by both Hearn, et al. (1976) and Herd (in press) with good agreement, although Herd maps a more complex fault zone. This well-defined north-trending fault zone is characterized by geomorphic features indicating probable Holocene activity, such as closed depressions, ponded alluvium, linear troughs, a deflected drainage, and well-defined scarps (figures 2b, 3b).

Red Hill Road Fault

The Red Hill Road fault, located along a northwest trend in sections 4, 9, and 10, T12N, R8W, is locally well-defined just north and south of Red Hill Road (figures 2a, 3a). The fault is characterized by a linear trough and a west-facing scarp near locality 17 (figures 3a, 3b). Farther southeast, the fault is characterized by a subtle trough, possible closed depressions, and a sidehill bench (locality 18, figures 2a, 3a). Although Hearn, et al. (1976) extend the fault zone farther southeast than Herd (in press), the faults are not well-defined (figure 2a).

Faults in Lower Lake Quadrangle

North-northwest-trending faults on the top of Quackenbush Mountain are well-defined and are characterized by geomorphic features suggestive of Holocene activity, such as ponded alluvium, a sidehill bench, and well-defined scarps in early Pleistocene-age basalt (locality 19, figures 2e, 3c). These faults are relatively short and do not seem to affect drainages in the area.

The northwest-trending fault near Schoolteacher Hill is characterized by a northeast-facing scarp in Plio-Pleistocene Cache Formation and early Pleistocene basalt (figures 2e, 3c). The scarp is moderately well-defined within the basalt, but is poorly defined in the Cache Formation, suggesting that the scarp may be erosional.

The south-facing scarp mapped by Hearn, et al. (1976) in Burns Valley is not well-defined and is probably due to lateral stream erosion (locality 9, figure 2c). No geomorphic evidence of recent faulting in alluvium was observed.

Herd maps a northeast-trending zone of faults just north of Anderson Flat (figure 3c). The faults are well-defined and are characterized by both east- and west-facing scarps. However, the faults do not extend into the alluvium.

7. Field Checking

A three-day field reconnaissance was made in the Clear Lake area to confirm the location of key fault zones and, if possible, to find additional evidence of Holocene activity. Field mapping within the Clear Lake volcanic field is extremely difficult due to exceptionally dense chaparral (photo 1). In addition, exposures are limited, and a thick soil cover forms over most of the volcanic rocks in the area.

A fault exposed in an artificial cut within the Konocti Bay fault zone was observed by this writer at locality 20 (figure 3a). The fault strikes about N25°W and dips 70°E (photos 2a, 2b). Colluvium on the west is offset against pyroclastic deposits (bp unit of Hearn, et al., 1976). There is an apparent scarp facing to the west associated with shears extending to about 1 to 2 feet from the ground surface. However, a large amount of grading has occurred within the area, and it is not known if the ground surface above the fault zone is natural or artificial. Interpretation of 1942 USGS air photos indicates that a backfacing scarp (facing to the west) delineated a strand of the Konocti Bay fault zone very near this artificial cut. Thus, this fault exposure may coincide with the principal western trace of the Konocti Bay fault zone mapped by Hearn, et al. (1976) and Herd (in press). Additional steeply east-dipping shear zones were observed to the east of this fault exposure.

Minor shears in rhyolite and rhyolitic tuff were observed in a roadcut along the northeast-trending fault near Mt. Olive (locality 21, figure 3b). The principal fault plane was not observed in the roadcut, although it was probably located within a drainage just southeast of where the minor shears were exposed.

A roadcut exposure along Soda Bay Road east of Sugarloaf (locality 22, figures 2a, 3a) revealed some of the complexities of faulting within the Clear Lake area. A 40°N-dipping thrust fault offsets young pyroclastic deposits (bp unit of Hearn, et al., 1976) (locality 22, figures 2a, 3a). The thrust fault is delineated by a well-defined, south-facing scarp that is mapped by both Hearn, et al. (1976) and Herd (in press). The fault scarp is set back (north) from the exposed fault about 10 to 15 feet, suggesting that the scarp may, in part, be erosional. A thin soil overlies the bp unit, and there is no evidence of offset or thickening of the soil over the hanging wall of the fault. It is not clear whether this thrust is caused by tectonic processes, or by local stresses related to volcanic activity and caldera collapse.

An artificial channel cut exposed rocks along the Red Hill Road fault at locality 17 (figures 3a, 3b). Although no shears were observed in the exposure, alluvium, undoubtedly of Holocene-age, was juxtaposed against rhyolitic tuff (0.5 my old rrp unit of Hearn, et al., 1976). The alluvium is probably reworked colluvium that was deposited adjacent to the west-facing scarp that characterizes the Red Hill Road fault. Beds in the alluvium are horizontal, with no evidence of offset. About 300 to 400 feet north of locality 17, and about 200 feet east of the projected trace of the fault, a man-made channel exposed extremely resistent, near vertically dipping welded tuff (figure 3b). This resistant unit trends parallel to the Red Hill Road fault and, although the near-vertical dip indicates probable tectonic deformation, the resitant nature of the tuff suggests that the west-facing scarp may be erosional. Occasional outcrops of this resistant welded tuff along the east side of the fault (south of the artificial channel) and the deposition of stream alluvium along the base of the scarp further support at least an enhancement by erosion of the Red Hill Road fault scarp.

8. Conclusions

Faults in the Clear Lake volcanic field form an extremely complex pattern as mapped by both Hearn, et al. (1976) and Herd (in press) (figures 2a-2c, 3a-3c). Hearn, et al. (1976, 1981) state that faulting in this region is primarily related to the San Andreas fault system, with an overprint of faulting caused by volcanic processes. In contrast, Herd (in press; p.c., 1982) interprets faulting in Clear Lake to be primarily the result of volcanic processes, including caldera subsidence as magma has been extruded. Both explanations have merit, but because most of the faults in the Clear Lake region have normal displacements, it is often difficult to distinguish between volcanic and tectonic origins.

Many of the features in the Clear Lake volcanic field assumed to be related to constructional volcanic processes and local collapse features may not constitute a future hazard with respect to significant surface rupture. Some of the features that are probably associated with volcanic domes or other localized vents or fissures include the arcuate faults flanking Mt. Hannah (figures 2a, 2b), and the faults on Quackenbush Mountain and northeast of Highway 53 near Anderson Flat (figure 2e). The displacement along these features probably represents a one-time event, with little chance of recurring displacement.

Most of the suspected volcanic or collapse features are relatively short and occur within a specific volcanic unit. Thus, fault length or continuity of the fault zone is one possible criterion for differentiating between collapse or volcanically related features and suspected tectonic features (or larger collapse features) that may have a potential for future surface displacement.

Konocti Bay Fault Zone

The Konocti Bay fault zone is a very wide zone of generally well-defined faults. The KBFZ is bounded on the east and west by well-defined, generally N25°W-trending faults that are characterized primarily by normal displacement, although a component of right-lateral strike-slip displacement is suggested by: (1) geomorphic features such as right-laterally deflected drainages and sidehill benches, and (2) earthquakes probably associated with this fault zone that have selected focal-plane solutions indicating right-lateral strike-slip offset (Bufe, et al., 1981). A wide zone of north, northeast, and east-west-trending faults located in the Wheeler Point area are well-defined and are characterized by normal displacement. Geomorphic features indicating possible Holocene activity are abundant along the principal northwest-trending faults in the Konocti Bay fault zone (figures 2a, 3a). Hearn, et al. (1976) map pyroclastic deposits (bp unit) ranging in age from 84,000 yrs to 11,000 yrs BP as offset by the Konocti Bay fault zone (figure 2a). However, it is not known what the specific age of the bp unit is where offset by the KBFZ (Donnely-Nolan, p. c. 8-82). An exposure of a strand of the KBFZ at locality 20 (figure 3a) revealed a N25°W, 70°E shear zone that offsets colluvium and extends to within 1-2 feet of the ground surface (photo 2), indicating late-Pleistocene and possible Holocene displacement. However, this is an artificial exposure, and it is uncertain if the ground surface is natural or has been disturbed by man.

Collayomi Fault Zone

The Collayomi fault zone is not well-defined along most of its mapped traces. Evidence of late-Pleistocene offset was observed by Hearn, et al. (1976) along Bottle Rock Road where silica-carbonate rock is thrust over Pleistocene gravel deposits (figure 2c). Clasts from volcanic rocks dated at 600,000 yrs BP were identified in the terrace deposits (McLaughlin, p. c., 8-82). McLaughlin (p. c. 8-82) indicates that this is the youngest known offset along the Collayomi fault zone. Hearn, et al. (1981) indicate a slip rate of 1mm/year along the Collayomi fault zone, but this is speculative, based entirely on inferred geologic data. Segments of the Collayomi fault zone are locally well-defined, such as at Camel Back Ridge (figures 2b, 3b). Evidence of possible Holocene activity along the Collayomi fault zone has not been observed. Small earthquakes are common in the area southwest of the Collayomi fault zone and although some events plot near the fault zone, there is no specific association with the fault zone.

Big Valley Fault

The Big Valley fault is locally well-defined and is delineated by geomorphic evidence of possible Holocene activity. Hearn, et al. (1981) state that the southern Big Valley fault ruptured during the 1906 San Francisco earthquake, based on cracks described the Lawson Report (Lawson, p. 188, 1908). However, it is speculation to assign historic activity to this fault based on reported cracks because alternative causes of cracking, such as liquefaction or differential settlement, are much more likely to have occurred.

Northeast-trending Faults South of Mt. Konocti

Northeast-trending faults located south of Mt. Konocti, mapped by Herd (in press) and Hearn, et al. (1976), are generally well-defined, and some are characterized by geomorphic evidence suggesting Holocene activity (figures 2b, 3b).

Red Hill Road Fault

The Red Hill Road fault is a generally well-defined, northwest-trending fault. The fault is characterized by a west-facing scarp, linear troughs, a sidehill bench, and possible closed depressions, suggesting Holocene activity (figures 2a, 3a). A fault plane was not observed in an artificial exposure that crossed the fault trace. However, the deposition of very recent stream alluvium may have obscured or destroyed evidence of offset in the near surface at this location.

Faults in Lower Lake Quadrangle

Faults at localities 8, 9, and 19 in the Lower Lake quadrangle are generally well-defined, although they are located within Pleistocene-age basalt and Plio-Pleistocene Cache Formation and do not offset alluvium. The well-defined faults are discontinuous and generally are less than a mile in length.

9. Recommendations

Recommendations for zoning faults for special studies are based on the criteria of sufficiently active and well-defined (Hart, 1980).

Clearlake Highlands Quadrangle

Zone for special studies well-defined traces of the Konocti Bay fault zone, the Red Hill Road fault, and a portion of the northeast-trending fault zone south of Mt. Konocti as indicated on figure 6a, based on mapping by Herd (in press) and Hearn, et al. (1976).

Kelseyville Quadrangle

Zone for special studies well-defined traces of the northeast-trending fault zone south of Mt. Konocti and the Big Valley fault as indicated on figure 6b, based on mapping by Herd (in press) and Hearn, et al. (1976).

Do not zone the Collayomi fault zone. This fault zone is not sufficiently active or well-defined.

Lower Lake Quadrangle

Do not zone for special studies faults in the Lower Lake quadrangle.

Whispering Pines Quadrangle

Do not zone for special studies faults in the Whispering Pines quadrangle.

The Geysers Quadrangle

Do not zone for special studies faults in The Geysers quadrangle (Collayomi fault zone).

10. Report prepared by William A. Bryant, September 10, 1982.

William A. Bryant

Recommendations seem reasonable, considering the complexity of the area.
Earl W. Hart
10/18/82

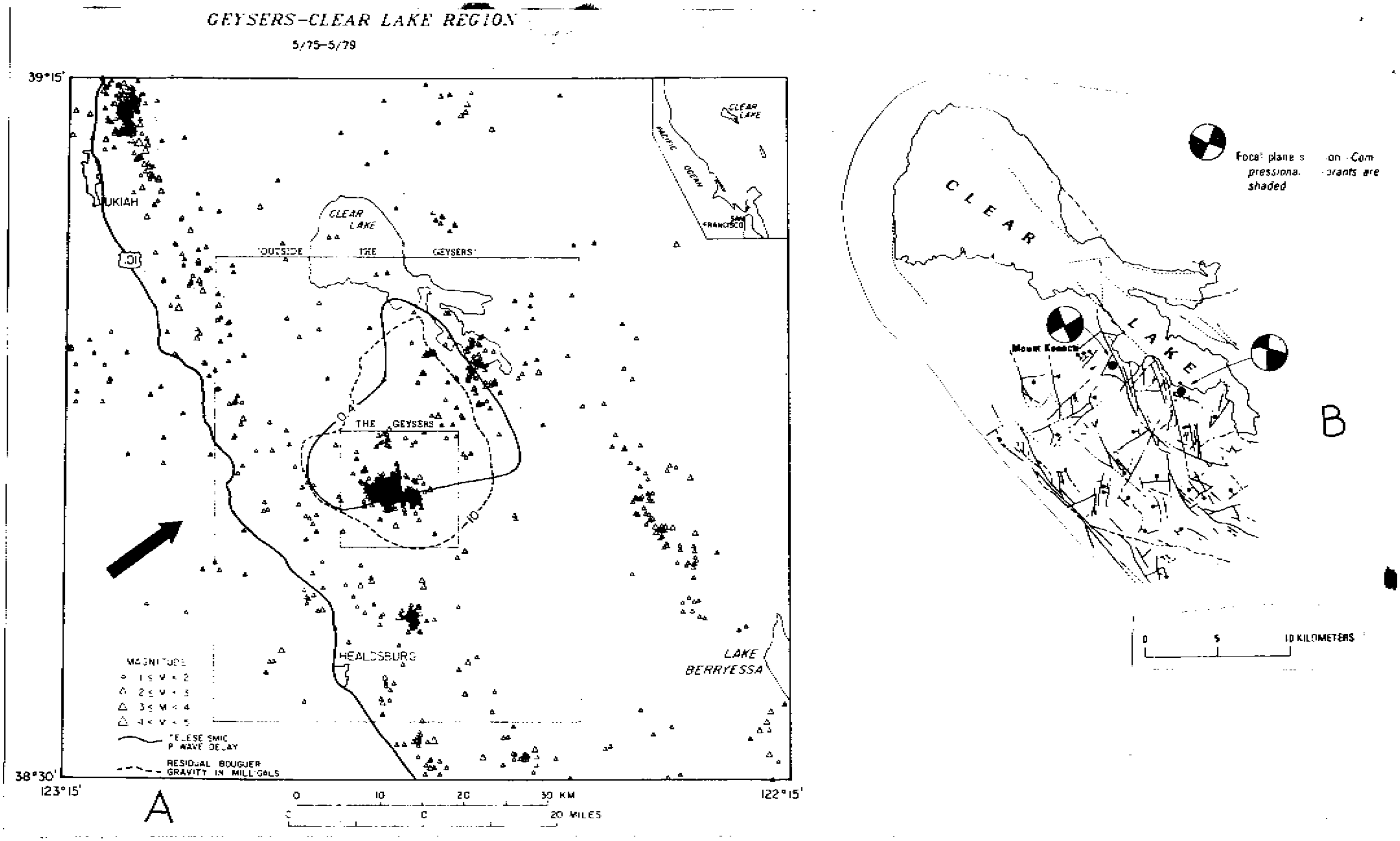

Figure 5 (to FER-132). Regional seismicity of The Geysers-Clear Lake area. A) Seismic activity is associated with the Maacama fault zone on the west and The Green Valley fault zone on the east. Significant clustering of seismicity occurs at The Geysers. Seismicity just east and west of Konocti Bay may be associated with the Konocti Bay fault zone. (A through C quality data; map from Ludwin and Bufe, 1980). B) Focal-plane solutions (lower hemisphere) for earthquakes that occurred September 29, 1975 (left) and August 16, 1976 (right). These seismic events may be associated with the Konocti Bay fault zone. (Map from Bufe, et al, 1981).

Photo 1 (to FER-132). Faults in the Wheeler Point area, view to the southeast. This photo illustrates the dense chaparral that has developed on the Clear Lake volcanics, obscuring or concealing much geologic evidence. Houses in the central middleground are constructed on a backfacing scarp that delineates a segment of the eastern part of the Konocti Bay fault zone.

Photo 2a (to FER-132). General view, looking north, of the northern Konocti Bay and Fraser Point (right side of photo). The east flank of Mt. Konocti is located on the left side of the photo. A segment of the Konocti Bay fault zone is characterized by a sidehill bench (arrows). An artificial cut (bare area in center of photo) exposes a branch of the Konocti Bay fault zone (tonal contrast between red-brown and light tan material). See photo 2b for detailed view of fault.

Photo 2b (to FER-132). Detailed view of a branch of the Konocti Bay fault zone; view to the northwest. The fault plane strikes N25°W and dips 70°E. Young pyroclastic deposits (bp unit of Hearn, et al, 1976) on the right are faulted against colluvium on the left, indicating a vertical component of displacement that is down to the west (left). An extremely crude set of sub-horizontal grooves observed on the shear surface suggests a component of horizontal displacement. Interpretation of 1942 U.S.G.S. air photos indicates that a west-facing scarp existed in approximately this location, which has now been modified by grading. An apparent scarp at the ground surface coincides with the location of the fault plane. However, it is not known to what extent the ground surface has been modified by grading.